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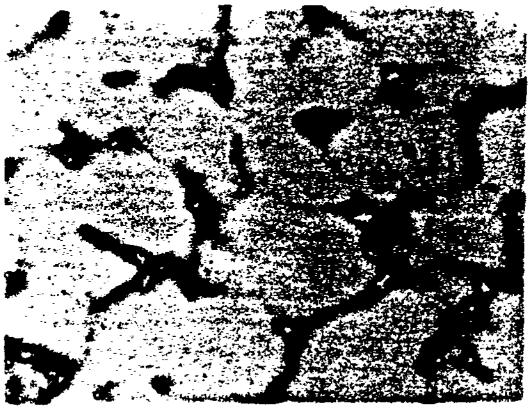
(54) **High-strength nickel-base superalloy for castings, treated by means of hot isostatic pressing.**

(57) A nickel base superalloy composition useful in the cast + HIP + heat treated condition is described. Articles having the invention composition have properties which are significantly better than similarly processed IN718 articles. This is achieved by modifying the chromium, columbium, and titanium contents in the alloy composition, relative to the IN718 composition.

FIG. 1b



Alloy9 : 13%Cr

This invention relates to cast nickel base superalloys, and in particular to compositions useful in casting large structural components for use in gas turbine engines.

Superalloys are materials, usually based on nickel, cobalt, or iron, which have useful mechanical properties at temperatures on the order of 538°C (I000°F) and above. Because of their desirable properties, superalloys have found numerous applications in gas turbine engines. In general, components for gas turbine engines are either cast, fabricated by powder metallurgy techniques, or are fabricated and machined from thermo-mechanically worked product forms such as forgings, plate, and sheet. Some alloy compositions particularly useful in wrought form are described in U.S. Patent Nos. 3 046 I08, 3 758295 and 4 23I 795. It is a result of thermo-mechanical working that articles having such compositions achieve their desired microstructure and properties. Without such processing these prior art compositions may not be useful. See, e.g. , the discussion in US-PS 3 046 I08 at column 3 starting at line 3I. The microstructure and properties of wrought products often are not realized in large, complex castings because of a slow cooling rate during solidification of the castings, which results in a coarse grain size and segregation. While fabrication and machining of complex components from various thermally-mechanically worked product forms is possible, the process is labor intensive and produces much scrap. For these reasons, it is quite expensive, and the use of castings is preferred. Sometimes, castings are hot isostatically pressed (HIP'd) to enhance properties.

The well known nickel base superalloy INCONEL ® Alloy 7I8 has been used by the gas turbine engine industry for many years. INCONEL is a registered trademark of The International Nickel Company, Inc. Hereinafter, INCONEL Alloy 7I8 will be referred to as IN7I8. This alloy is described in Aerospace Materials Specifications (AMS) 5663 (wrought materials) and 5383 (cast materials). According to AMS 5383, the composition range for IN7I8 is, by weight percent, 50-55 Ni, I7-2I Cr, 4.75 -5.5 Nb + Ta, 2.8-3.3Mo, 0-ICo, 0.65-I.I5 Ti, 0.4-0.8 Al, 0.0-I.75 Al + Ti, 0.0-0.35 Si, 0.0-0.006 B, 0.0-0.3Cu, 0.0-0.0I5 S, 0.0-0.0I5P, 0.0-0.35 Mn, 0.0-0.I0C, with the balance Fe.

Advanced engine designs have been proposed which require an alloy which can be cast to near-net shape into large complex components, with the added requirement that the alloy have greater tensile properties than IN 7I8. Cast components made of such a new alloy could replace components which are currently fabricated from wrought IN7I8 products, with no resultant weight penalty and at a cost savings. Also, due to the requirement that this new alloy be stronger than IN7I8, castings of the new alloy could replace IN7I8 castings, with a weight savings and at equal or less cost.

A development program was initially conducted to examine the possiblity of investment casting IN7I8 into large structural components for gas turbine engines. Even after solving many casting related problems, porosity, segregation, and inclusions were still present in the castings at undesirable levels. In castings which solidified slowly, a significant amount of Laves phase was present in interdendritic areas. Laves phase significantly degrades the weldability and mechanical properties of castings. Defects such as porosity and inclusions are also detrimental to mechanical properties; all three of these defect types must be eliminated if the use of large IN7I8 cast components is to become practicable.

The alloys of the present invention result from a program to develop alloys which are stronger in the cast + HIP + heat treated condition than similarly processed IN7I8, and which have tensile properties which approach those of wrought IN7I8 products. Also, the alloys must be capable of being cast into large, complex, and near-net shapes, and must be weldable.

The alloys of the present invention are modifications of the IN 7I8 composition. Castings made of the invention alloys are useful in the non-wrought condition. In the cast + HIP + heat treated condition, these articles have significantly improved tensile properties compared to similarly processed IN7I8 articles. These improvements result from increasing the Nb + Ta content to levels up to about 6.5%, and by increasing the Ti content to levels up to about 2.5%. Tungsten may optionally be present in amounts up to about 6.5%. The alloys have a reduced tendency for the precipitation of Laves phase during solidification, as compared to IN7I8; this is achieved by limiting the Cr content in the alloys to between about I0-I5%, and by decreasing the minimum Mo content to zero. The composition range for the alloys of the invention is, by weight percent, 5.25-6.25 Nb + Ta, 0.65-2.25 Ti, 0-6.5 W, I0-I5Cr, 0-3.3 Mo, I5-24 Fe, 0.2-0.8 Al, with the balance Ni + Co.

The alloys of the invention are uniquely useful in that they may be cast into large, complex shapes, and are weldable. In the HIP'd + heat treated condition, articles having this composition exhibit at least about a 25% increase in 649°C (I,200°F) tensile properties compared to similarly processed IN7I8. As a result, the alloys may be used in applications which require better properties than cast IN7I8, or equivalent properties to wrought IN7I8.

The foregoing and other features and advantages of the present invention will become more apparent in the light of the following detailed description of the preferred embodiments thereof as illustrated in the accompanying drawing.

Figs. I and Ib are photomicrographs (I00X) showing the effect of chromium content on Laves phase formation; and

Figs. 2a -2d are graphical representations of the tensile data of Table V.

The alloys of the present invention are compositional modifications of the alloy IN7I8; in the cast + HIP + heat treated condition, articles having the invention composition have tensile properties which are significantly better than similarly processed IN7I8.

In order to identify a castable alloy composition which had better tensile properties than cast + HIP + heat treated IN7I8, a laboratory test program was conducted to determine the effect of various elements on the mechanical properties of castings having a composition similar to the average IN7I8 composition. Metallographic examination of these new alloys was also conducted to examine their propensity for Laves phase formation.

The compositions of the alloys evaluated are presented in Table I, as is the composition for IN7I8 specimens which were evaluated as a baseline. As is seen in the Table, the nominal Nb + Ta content in cast IN7I8 is 5.0 weight percent. Increased Nb + Ta contents of 5.5 and 6 weight percent were evaluated. The typical Ti content in IN7I8 is I.0 weight percent, and alloys containing I.5 and 2 weight percent Ti were evaluated. Alloys containing up to 6 weight percent Mo, and up to 6 weight percent W were evaluated. Chromium was reduced to I2 weight percent in some of these alloys. Iron was fixed at I8 weight percent, and Ni + Co was the "balance element". All alloys contained C.

The results of tensile tests conducted at 649°C (I,200°F) on specimens having the composition of the alloys of Table I are presented in Table II. As is seen in the Table, with only minor exceptions, all of the modified alloys had 0.2% yield strengths and ultimate tensile strengths which were improved compared to the IN7I8 baseline. The ductility measurements (i.e., elongation and reduction in area) for the modified alloys were, in general, reduced relative to the IN7I8 baseline. This was not unexpected, however, due to increased tensile properties of the modified alloys.

Metallographic examination of the alloy of Table II indicated that chromium exerted a significant influence on the amount of Laves phase in the as-cast microstructure. This was surprising, since the primary elements in Laves phase are Ni and Nb. The effect of Cr in these alloys can be seen in Figs. Ia and Ib. The specimens shown these figures were prepared using standard metallographic techniques. To highlight the Laves phase precipitate, the specimens were electrolytically etched with an aqueous solution containing I0% oxalic acid. In these photomicrographs, the Laves phase appears as the white phase in interdendritic regions. The dark phase surrounding the Laves is predominantly the gamma double prime strengthening phase, Ni_3Nb. The matrix phase in IN7I8 is a nickel solid solution, gamma. As is seen in the Figures, in an alloy containing I9% Cr, (Alloy I3 in Table I) there is a substantial amount of Laves phase in the microstructure, in the form of an interconnected network of precipitate. In an alloy containing I2% Cr - (Alloy 9 in Table I) the amount of Laves phase is considerably decreased. Also, the Laves phase in the Alloy 9 specimen is present as isolated pools of precipitate, as compared to the interconnected network for Alloy I3.

As a result of the increase in mechanical properties produced by the increased Nb, Ti and W contents, and the decrease in Laves phase caused by the decreased Cr content II3 kg (250 pound) vacuum induction melted (VIM) heats of material were prepared. The target composition range for these heats is given in Table III. The actual chemistry for the heats, referred to as HS I, HS 2, and HS 3, are also given in the Table.

As seen in the Table, all three alloys contained about I2% Cr; the alloys designated HSI and HS3 contained about 3% Mo while the alloy designated HS2 contained about I% Mo. HSI and HS2 contained nearly 6% Nb + Ta and 2% Ti, while HS3 contained about 5.5 Nb + Ta and I.5 Ti. Otherwise, the compositions were similar to a typical IN7I8 composition, except for the fact that, as in the alloys of Table I, the Fe content was fixed at about I8, and Ni + Co was the "balance" element.

To determine the mechanical properties of these modified alloys relative to IN7I8, two different engine components (which in current engines are cast IN7I8) were investment cast using techniques known in the art. Components of all four alloys (IN7I8, HSI, HS2 and HS3) were cast under substantially identical conditions, and then HIP'd at II90°C (2 I75°F) for 4 hours at I03,4 MPa (I5 000 psi) to close non-surface connected porosity. Following the HIP treatment, each component was heat treated to optimize mechanical properties. The heat treatment for IN7I8 specimens comprised a stabilization treatment at 87I°C (I 600°F) for I0 hours, a solution treatment at 954°C (I 750°F) for I hour, and a precipitation (aging) treatment at 732°C (I 350°F) for 8 hours, followed by a furnace cool at a rate of at least 55°C (I00°F) per hour to 663°C

(I 225°F) holding at 663°C (I 225°F) for 8 hours, and the cooling to room temperature. The heat treatment for all three modified alloys was similar to that for IN7I8, except that the stabilization treatment was eliminated, and the solution treatment took place at I05I°C (I 925°F) for I hour; the aging treatment was the same as for IN7I8. The results of tensile tests conducted at 2I°C (70°F) and 649°C (I 200°F) are presented in Tables IV and V. In Figs. 2a-2d, the 649°C (I 200°F) data from Table V has been averaged, and plotted in the form of a bar chart.

For use in modern gas turbine engines, cast + HIP + heat treated IN7I8 should have a minimum 649°C (200°F) 0.2% yield strength of about 620.5 MPa (90 000 psi), and a minimum 649°C (I 200°F) ultimate tensile strength of about 689.5 MPa (I00 000 psi). Reference to Tables IV and V, and to Figs. 2a-2d, indicates that the alloys of the invention, in the cast + HIP + heat treated condition, exceed these minimum property requirements by at least 25%. The alloy HS2, which had the best 0.2% yield strength and ultimate tensile strength of the three modified alloys at 649°C (I 200°F) , exceeded these minimum property requirements by more than 37%. The ductility of the three modified alloys is comparable to the ductility of IN7I8.

A comparison of the 649°C (I 200°F) tensile properties reported in Table II with those of Table V reveals some differences, even though the alloy compositions (Tables I, III) were similar. The observed differences are believed to be attributable to the fact that the solidification rate for the specimens of Table II was faster than the solidification rate for the specimens of Table V. The faster solidification rate resulted in a finer as-cast grain size, and better tensile properties.

Metallographic examination of as-cast HSI, HS2, and HS3 specimens revealed that due to their lower Cr content relative to IN7I8, they contained less Laves phase precipitate than the similarly processed IN7I8 castings. This was in agreement with the observations made with respect to the specimens shown in Fig. I.

The modified alloys were judged to have the same castability as IN7I8. "Castability" is a measure of the capability of an alloy to fill a mold and solidify without the formation of hot tears or excessive shrinkage porosity. In general, the fewer the number of defects detected, the better the alloy castability. In tests to evaluate the relative castability of the invention alloys with IN7I8, all materials successfully filled their molds and contained a comparable number of surface and subsurface defects. Thus, it was concluded that the alloys had comparable castability.

Large structural castings having the composition of the alloys of the present invention may be produced using casting techniques known in the art. A preferred method is to melt virgin stock by vacuum induction melting (VIM) and solidifying the melt in an investment casting mold. While the use of virgin stock is preferred, it is believed that revert, or scrap, material may also be used.

To close as-cast, non-surface connected porosity in the castings, the component should be HIP'd after casting. One HIP treatment which has yielded favorable reduction in porosity is II90°C (2 I75°F) for 4 hours at I03.4 MPa (I5 000 psi). However, those skilled in the art will recognize that other temperature, time, and pressure combinations may yield equally favorable results.

Because large, complex castings may contain as-cast defects such as surface connected porosity or inclusions, they must be weldable to repair such defects. The presence of Laves phase in the as-cast microstructure significantly increases the tendency for weld outgassing and generation of weld splatter. According to Vincent, "Precipitation Around Welds In The Nickel Base Superalloy, Inconel 7I8", Acta Metallurgica Volume 33, No. 7, pp. I205 -I2I6 (I985), Laves phase is also linked to the formation of heat affected zone microcracks. Tests conducted to date suggest that Laves phase will not form in the alloys of this invention to the extent which will adversely affect weldability. As a result, these alloys are considered to be weldable. It should be noted that the commonly assigned and co-pending application U.S. Serial No. 565 589, PRE-HIP HEAT TREATMENT OF SUPERALLOY CASTINGS, describes a heat treatment for dissolving as-cast Laves phase into the alloy matrix.

If defects such as porosity or inclusions are found in the casting after HIP'ing, such defects may be removed by e.g., abrasive grinding. These areas may then be weld repaired using, e.g., arc welding techniques. It is preferred that weld filler metal (e.g. , wire or rod) which has a composition within the range specified in Table III be used, in order to avoid any incompatibilities between the weld bead and base metal. Prior to welding, the component is preferably heat treated at I05I°C (I 925°F) for I hour (air cool). Following weld repair, the component is reinspected and if no further defects are found, the component is heat treated to optimize mechanical properties, according to the following schedule : I05I + I4°C (I 925° + 25°F) I hour, followed by 732 ± I4°C (I350° ± 25° F)/8 hours, furnace cool at a rate of about 55°C/(I00°F) per hour to 663°C (I225°F), followed by 663± I4°C (I225° ± 25°F)/8 hours (air cool).

Because of the desirable mechanical properties of cast articles having the composition of the invention, and in view of their weldability, they are useful in the fabrication of large, complex castings for use in turbomachinery such as gas turbine engines. They are particularly useful in the fabrication of components such as diffuser cases and rotor disks.

Although the invention has been shown and described with respect with a prefered embodiment thereof, it should be understood by those skilled in the art that other various changes and omissions in the form and detail thereof may be made therein without departing from the scope of the invention.

TABLE I

MODIFIED ALLOY COMPOSITIONS, WEIGHT PERCENT

Alloy	Nb + Ta	Ti	Mo	W	Cr	Al	C	Fe	Ni + Co
1*	5.0	1.04	3.0	0.0	19.0	0.42	0.052	18.1	Balance
2	5.0	1.04	3.0	6.0	12.0	0.41	0.048	18.1	Balance
3	5.0	1.03	6.0	0.0	12.0	0.38	0.049	18.1	Balance
4	5.0	1.03	6.0	6.0	19.0	0.40	0.062	18.1	Balance
5	5.0	2.02	3.0	0.0	12.0	0.40	0.040	18.2	Balance
6	5.0	2.04	3.0	5.9	19.0	0.40	0.062	18.1	Balance
7	5.0	2.03	6.0	0.0	19.0	0.36	0.053	18.1	Balance
8	5.0	2.00	6.0	6.0	12.0	0.39	0.046	18.1	Balance
9	6.0	1.04	3.0	0.0	12.0	0.42	0.052	18.1	Balance
10	6.0	1.00	3.0	6.0	19.0	0.42	0.064	18.0	Balance
11	6.0	1.01	6.0	0.0	19.0	0.39	0.062	17.9	Balance
12	6.0	1.00	6.0	6.0	12.0	0.40	0.040	18.0	Balance
13	6.0	2.00	3.0	0.0	19.0	0.41	0.062	17.9	Balance
14	6.0	1.99	3.0	6.2	12.0	0.41	0.046	18.0	Balance
15	6.0	2.00	6.0	0.0	12.0	0.40	0.054	18.0	Balance
16	6.0	2.00	6.0	6.0	19.0	0.40	0.055	18.0	Balance
17	5.5	1.47	4.5	3.0	15.5	0.42	0.046	18.0	Balance
18	5.5	1.50	4.5	3.0	15.5	0.40	0.048	18.0	Balance

* Typical IN718 composition

TABLE II

649°C (1,200°F) TENSILE PROPERTIES OF MODIFIED ALLOY COMPOSITIONS IN CAST + HIP + HEAT TREATED CONDITION*

Alloy	0.2% Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)	Reduction In Area (%)
1	817.0	917.7	9.5	22.0
2	1040.4	1121.1	9.0	14.3
3	831.5	914.2	12.5	16.1
4	809.4	1023.9	8.7	10.3
5	964.6	1051.4	7.0	12.1
6	974.9	1112.1	7.7	5.3
7	918.4	1005.2	6.0	2.7
8	1015.6	1113.5	6.0	7.8
9	1029.4	1096.3	6.4	10.3
10	998.3	1133.5	6.1	6.7
11	957.7	1051.4	5.2	5.6
12	1014.2	1065.9	5.3	6.8
13	1010.1	1066.6	10.2	21.9
14**	>1066.6	>1069.4	>2.1	>3.0
15	1097.6	1126.6	6.5	21.5
16	978.4	1163.8	2.0	1.4
17	978.4	1061.8	5.3	9.6

* Specimens heat treated to solutionize delta phase.

** Specimen failed prematurely.

TABLE III

HIGH STRENGTH ALLOY COMPOSITIONS, WEIGHT PERCENT

ELEMENT	COMPOSITION RANGE	HS1	HS2	HS3
Tungsten	0.0 - 6.5	0.0	0.0	0.0
Niobium + Tantalum	5.25 - 6.25	5.76	5.94	5.28
Titanium	0.65 - 2.25	1.91	1.90	1.44
Chromium	10.0 - 15.0	12.3	12.2	12.2
Molybdenum	0.0 - 3.30	2.96	1.12	2.95
Iron	15.0 - 24.0	18.3	17.9	18.5
Aluminum	0.20 - 0.80	0.50	0.54	0.52
Carbon	0.0 - 0.08	0.04	0.04	0.04
Cobalt	0.0 - 1.00	<0.10	<0.10	<0.10
Nickel + Cobalt	Balance	Balance	Balance	Balance
Manganese	0.0 - 0.35	0.02	0.02	0.02
Silicon	0.0 - 0.35	0.02	0.03	0.04
Phosphorus	0.0 - 0.015	<0.01	<0.01	<0.01
Sulfur	0.0 - 0.015	0.003	0.004	0.003
Boron	0.0 - 0.006	0.002	0.003	0.002
Copper	0.0 - 0.10	<0.10	<0.10	<0.10
Zirconium	0.0 - 0.05	<0.05	<0.05	<0.05
Lead	0.0 - 0.0010	<0.001	<0.001	<0.001
Bismuth	0.0 - <0.5ppm	<0.5ppm	<0.5ppm	<0.5ppm
Selenium	0.0 - 0.0003	<0.0003	<0.0003	<0.0003

TABLE IV

ALLOY TENSILE PROPERTIES AT 70°F; SPECIMENS MACHINED FROM CAST + HIP + HEAT TREATED ENGINE COMPONENTS

Alloy	0.2% Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)	Reduction In Area (%)
IN718	861.1	953.5	11.3	25.9
IN718	954.2	1028.0	8.4	11.7
IN718	955.6	1029.4	7.5	12.4
HS1	1068.0	1147.3	9.0	21.7
HS1	1168.7	1245.9	5.8	16.5
HS1	1152.1	1209.3	8.5	26.8

TABLE IV, continued

Alloy	0.2% Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)	Reduction In Area (%)
HS2	1096.9	1133.5	8.0	26.5
HS2	1198.3	1248.6	9.0	19.7
HS2	1198.3	1240.4	10.8	28.9
HS3	1025.2	1123.8	14.0	26.7
HS3	1041.8	1118.3	14.8	21.9

TABLE V

ALLOY TENSILE PROPERTIES AT 649°C (1 200°F); SPECIMENS REMOVED FROM CAST + HIP + HEAT TREATED ENGINE COMPONENTS

Alloy	0.2% Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)	Reduction In Area (%)
IN718	739.8	812.9	13.4	34.3
IN718	682.6	739.8	14.6	29.3
IN718	732.2	768.7	10.7	21.9
IN718	710.8	775.6	12.0	28.9
HS1	844.6	880.4	8.3	35.8
HS1	904.6	952.1	8.5	33.2
HS1	886.6	923.2	7.0	20.4

TABLE V, continued

Alloy	0.2% Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)	Reduction In Area (%)
HS1	930.1	969.4	7.5	28.1
HS2	900.4	942.5	9.0	27.3
HS2	949.4	1010.8	8.6	28.7
HS2	914.2	953.5	9.5	31.4
HS2	925.9	1008.0	10.6	18.3
HS3	824.6	868.7	9.0	24.4
HS3	812.9	869.4	11.0	23.2

Claims

I. An alloy composition which normally consists essentially of, by weight percent, I7-2I Cr, 50-55 Ni + Co, 2.8-3.3 Mo, 4.75 -5.5 Nb + Ta, 0.65-I.I5 Ti, 0.4-0.8 Al, with the balance Fe, wherein castings made of said alloy have an as-cast microstructure containing gamma double prime, gamma prime, and Laves phase precipitates, characterized by the improvement which comprises increasing the Nb + Ta content to between about 5.5 and 6.5 to increase the amount of gamma double prime phase in castings made of the alloy, and decreasing the Cr content to between about I0 and I5 to decrease the amount of Laves phase in castings made of the alloy, said castings being useful in the non-wrought condition and weldable.

2. The alloy according to claim I, characterized by the further improvement which comprises increasing the Ti content to between about I.I5 and 2.25 to increase the amount of gamma prime phase in castings made of the alloy.

3. The alloy according to claim 2, characterized by the further improvement which comprises adding up to about 6.5 w.

4. The alloy according to claim 3, characterized by the further improvement which comprises decreasing the Mo content to between about 0.0 and 3.3% in order to further decrease the amount of Laves phase in the castings made of the alloy.

5. The alloy according to claims I-4, characterized by the further improvement which comprises limiting the Fe content to between about I5 and 24, while modifying the Ni + Co content such the Ni + Co makes up the balance of the alloy composition.

6. A gamma double prime-gamma prime strengthened nickel base superalloy for use in the cast + HIP + heat treated condition, and having a decreased tendency for Laves phase formation during solidification , characterized in consisting essentially of, by weight percent, 0.0-3.3 Mo, I5-24 Fe, 0.2 -0.8 Al, 0.65-2.25 Ti, 5.25 -6.5 Nb + Ta, 0-6.5 W, with the balance Ni + Co.

7. A method for making a cast, gamma double prime-gamma prime strengthened nickel base superalloy article useful in the non-wrought condition, characterized in comprising the steps of :

(a) melting and solidifying an alloy having a composition consisting essentially of, by weight percent , 0.0-3.3 Mo, I5-24 Fe, 0.2-0.8 Al, 0.65-2.25 Ti, 5.25-6.5 Nb + Ta, I0-I5Cr, 0-6.5 W, with the balance Ni + Co, wherein the high Ti and Nb contents promote the formation of the gamma double prime and gamma prime phases in the micro-structure, and the low Cr content suppresses the formation of Laves phase in the microstructure ;

(b) HIP'ing the cast alloy at conditions to close as-cast, subsurface porosity; and

c) heat treating to optimize mechanical properties.

8. A method for increasing the amount of gamma double prime phase while decreasing the amount of Laves phase which forms during the solidification of an alloy which normally consists essentially of, by weight percent, I7-2I Cr, 50-55 Ni + Co, 2.8 -3-3 Mo, 4.75 -5.5 Nb + Ta, 0.65-I.I5 Al,0.4 -0.8 Al, with the balance Fe, characterized in comprising the steps of increasing the Nb + Ta content to between about 5.5 and 6.5 percent, and decreasing the Cr content to between about I0 and I5 percent.

9. The method according to claim 8, characterized in further comprising the step of decreasing the Mo content to between 0.0 and 3.3 percent.

I0. A method for increasing the amount of gamma double prime and gamma prime phase, while decreasing the amount of Laves phase which forms during the solidification of an alloy which normally consists essentially of, by weight percent, I7-2I Cr, 50-55 Ni + Co, 2.8 -3.3 Mo, 4.75 -5.5 Nb + Ta, 0.65-I.I5 Al, 0.4-0.8 Al, with the balance Fe, characterized in comprising the steps of increasing the Nb + Ta content to between about 5.5 and 6.5 percent, increasing the Ti content to between about I.I5 -2.25 percent, and decreasing the Cr content to between about I0 and I5 percent.

II. The method of claim 8, characterized in further comprising the step of decreasing the Mo content to between 0.0 and 3.3 percent.

I2. A method for increasing the tensile strength of INCONEL Alloy 7I8, characterized in comprising the steps of increasing the Nb + Ta content in the alloy composition to between about 5.5 -6.5 weight percent and decreasing the Cr content to between about I0-I5 weight percent, wherein castings made of the alloy are useful in the non-wrought condition and are weldable.

I3. The method according to claim I2, characterized in further comprising the step of increasing the Ti content to between about 0.65-2.25 weight percent.

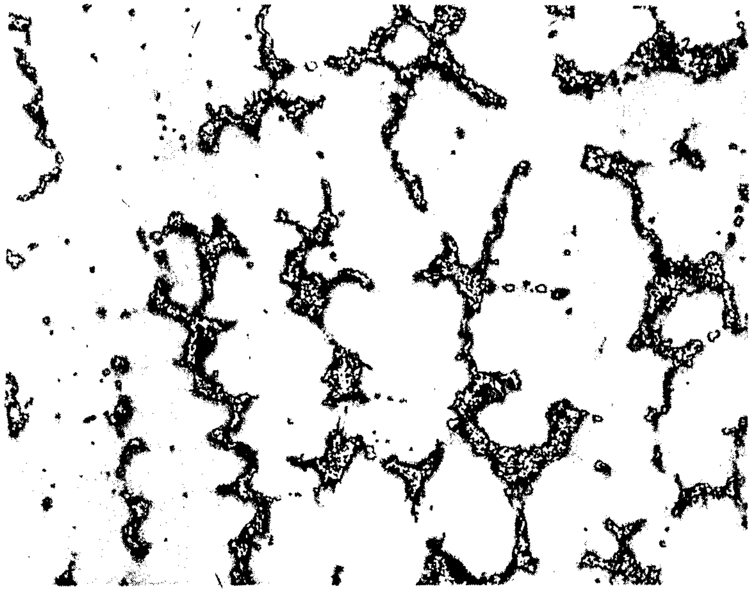
I4. The method according to claim I3, characterized in further comprising the step of adding up to about 6.5 weight percent tungsten.

I5. The method according to claim I4, further comprising the step of decreasing the Mo content to about 0.0-3.3 weight percent.

I6. An article made by the method of claim I2.

I7. An article made by the method of claim I5.

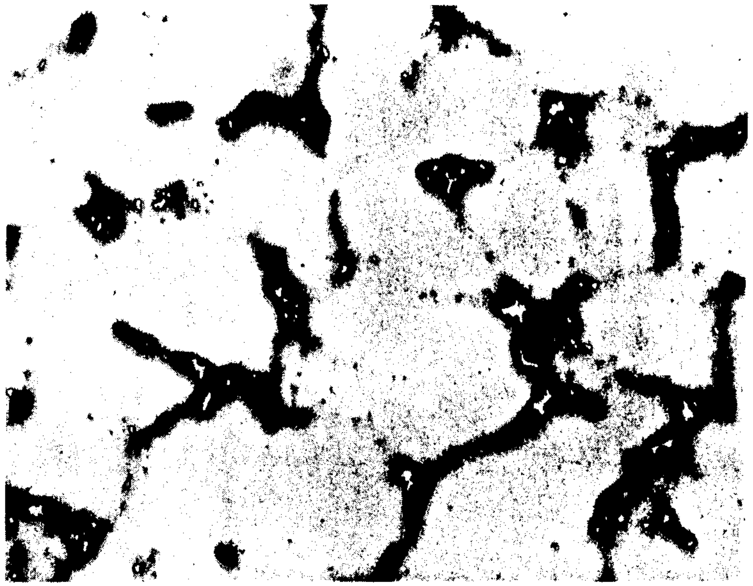
FIG. 1a



100X

Alloy 13 : 19%Cr

FIG. 1b



100X

Alloy9 : 13%Cr

FIG.2a

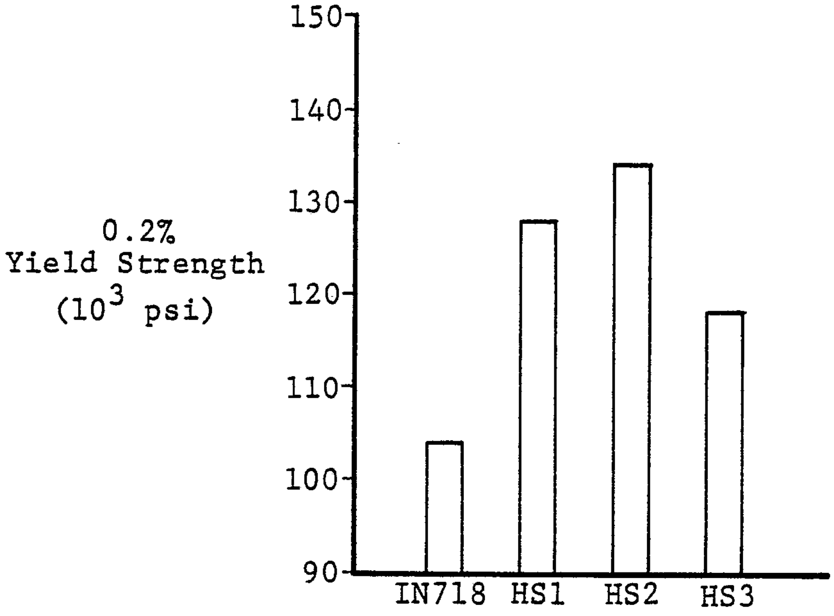

0.2%
Yield Strength
(10^3 psi)
150
140
130
120
110
100
90
IN718
HS1
HS2
HS3

FIG.2b

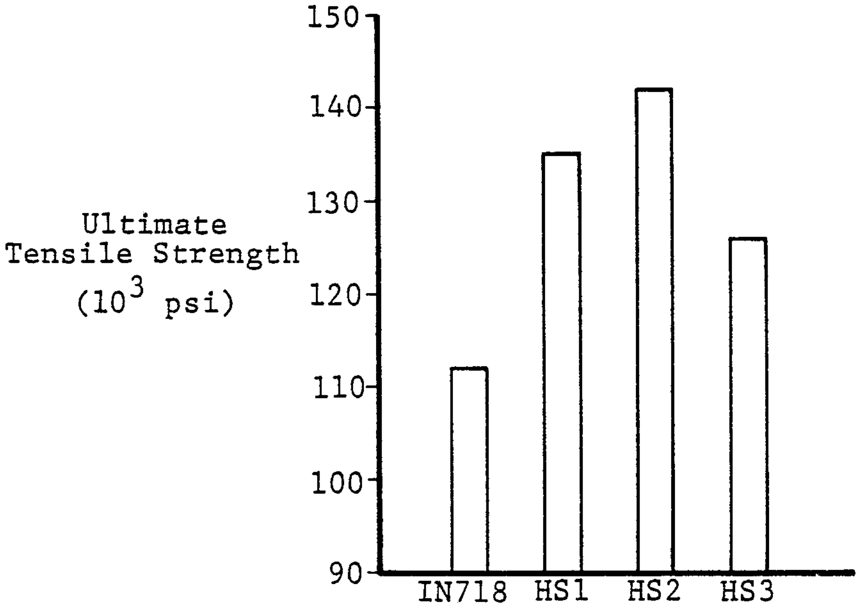

Ultimate
Tensile Strength
(10^3 psi)
150
140
130
120
110
100
90
IN718
HS1
HS2
HS3

FIG. 2C

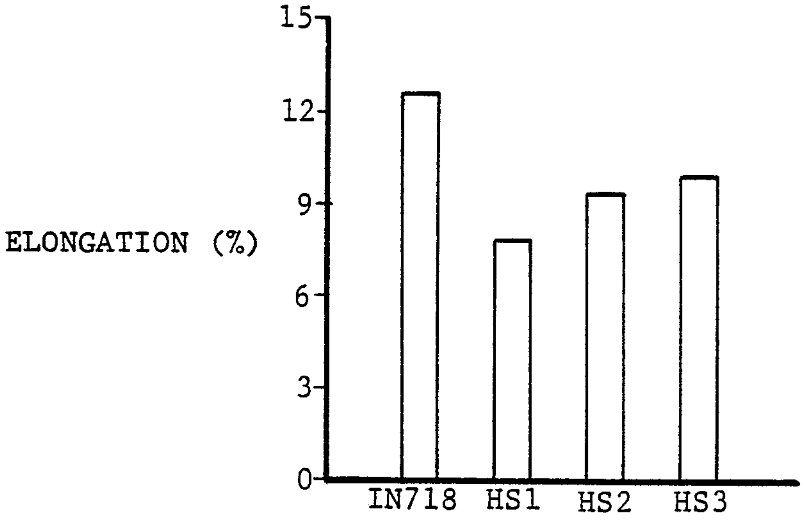
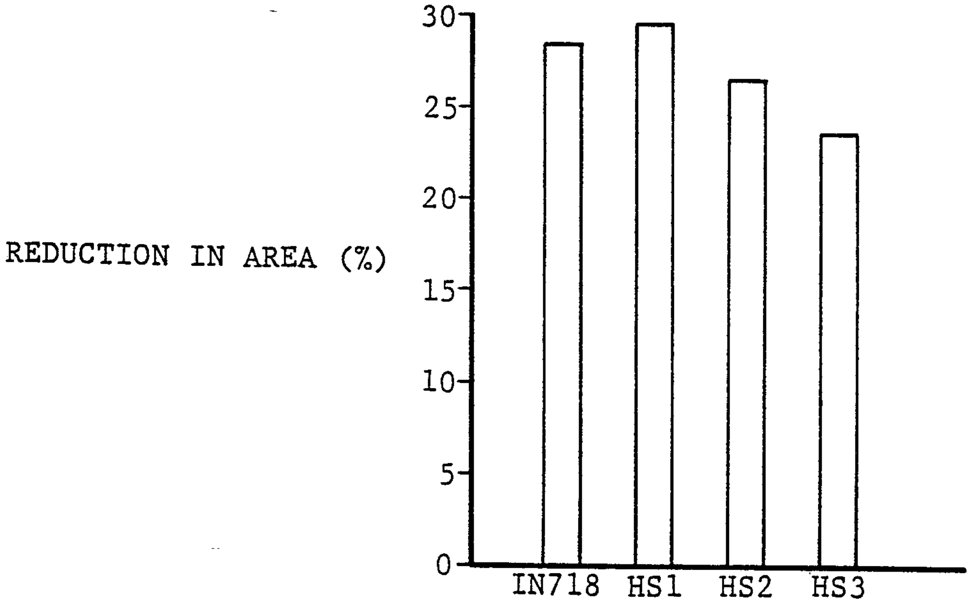

15
12
9
6
3
0
ELONGATION (%)
IN718
HS1
HS2
HS3

FIG. 2d


30
25
20
15
10
5
0
REDUCTION IN AREA (%)
IN718
HS1
HS2
HS3